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JOSÉ MARIA CALAFORRA*, PAOLO FORTI**

THE CLIMATE DRIVEN PECULIAR SPELEOTHEMS OF THE NATUTURINGAM CAVE (PUERTO PRINCESA UNDERGROUND RIVER, PALAWAN, PHILIPPINES): A REVIEW

RIASSUNTO

Grazie alle recenti spedizioni e conseguenti studi, è stato messo in evidenza come la Grotta Natuturingam (più conosciuta attualmente come PPUR, acronimo di Puerto Princessa Underground River) ospiti una notevole quantità di speleotemi rari ed anche del tutto nuovi per l'ambiente di grotta. Queste concrezioni inusuali si sono sviluppate essenzialmente nelle gallerie alte, dove è minimo l'effetto dell'acqua marina, che allaga due volte al giorno le gallerie principali della grotta al livello di base. La genesi e l'evoluzione di questi speleotemi è stata costantemente controllata dal particolare clima di Palawan, caratterizzato da improvvisi forti temporali, che inducono enormi variazioni nel regime di alimentazione idrica degli speleotemi medesimi.

Nel presente lavoro viene fornito un quadro riassuntivo sulla genesi di quei nuovi speleotemi che sono già stati studiati ("colate a gradini", "stelle di ghiaccio", "erba di grotta", "coppa di champagne", "i ricci di mare" e "le meduse"), mentre viene discussa in dettaglio quella delle forme ancora non descritte (i monocristalli sferoidali di calcite, le pisoliti lenticolari e cilindriche, "la stalattite a mazza ferrata" e i "cappelli di calcite").

Alla fine si sottolinea l'importanza planetaria della grotta Natuturingam, dato che alla luce di queste ricerche risulta essere attualmente la cavità naturale che ospita il maggior numero di speleotemi peculiari al mondo.

Parole chiave: Speleotemi, clima tropicale, Palawan.

ABSTRACT

Thanks to the recent expeditions and studies, it was put in evidence the abundance of very peculiar speleothems hosted and sometime restricted within Natuturingam cave (better known as Puerto Princessa Underground River AKA "PPUR"). The uncommon formations are mainly located in the higher galleries of the cave, corresponding to the upper limestone formation, far from the influence of the sea which tide floods twice a day the main galleries at the base level. The genesis and evolution of these speleothems were always controlled by the Palawan climate characterized by sudden strong rainstorms, which cause a tremendous variation in the speleothem feeding regime.

In the present paper a short overview on the genesis on the already described new speleothems (ribbed drapery, frozen stars, cave grass, champagne flute and sea urchins) is given, while that of the still

* La Venta Esploraciones Geográficas & Universidad de Almería, Spagna.

** La Venta Esploraciones Geográficas & Istituto Italiano di Speleologia, Bologna, Italy
paolo.forti@unibo.it

undescribed ones (spheroidal calcite monocrystals, lenticular and cylindrical cave pearls, spike mace stalactite, calcite caps) are discussed in detail. Finally, the worldwide importance of the Natuturingam cave is stressed, being one of the richest shelter in the world of uncommon and/or new speleothem types.

Keywords: *Speleothems, tropical climate, Palawan.*

INTRODUCTION

The Natuturingam cave (better known as PPUR, acronym of Puerto Princesa Underground River) is one of the largest subterranean estuaries of the world, where tides propagate over 6.5 km inside the cave. Actually it consists of over 34 km of giant galleries, which host an extremely complex ecosystem based on the huge colonies of bats and swiftlets. Its natural uniqueness was recognized as World Heritage by UNESCO since 1999, while the first 2 km of its navigable branch was transformed into a show cave some 20 years earlier (Fig 1), thus be-

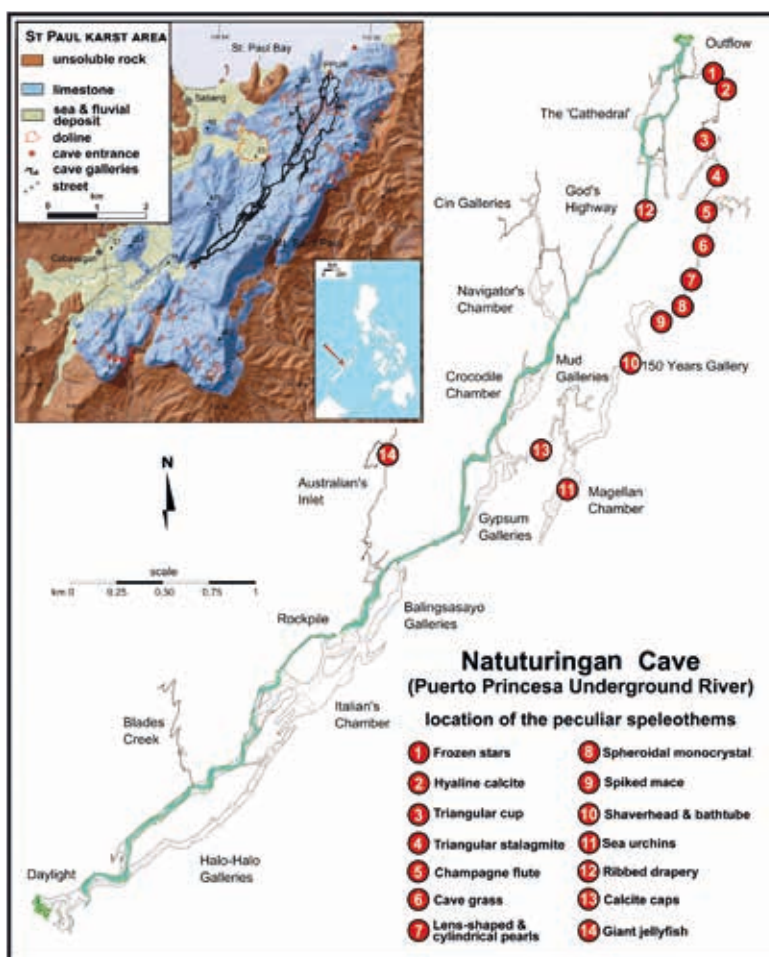


Fig. 1 - Index map, geological sketch and plan view of Natuturingam cave with the location of the actually known uncommon/new speleothems (after DE VIVO ET AL., 2013, modified).

coming, in the third millennium, the most visited show cave of the Philippines and one of the most visited of the whole far East Asia, with some 300.000 visitors/year. A peculiarity of this cave is that, even been visited by more than 300.000 people/year, no fixed structures at all have been settled up inside it, which therefore should be still considered as a totally pristine cave.

A peculiarity of Natuturingam cave is represented by its average temperature: in fact it is one of the hottest meteoric caves of the world. The underground climate is extremely stable, being controlled by the general island climate (BADINO, 2013) and by the sea tide, which, during the dry season, invades every about 12 hours a large part of the cave with more than 100.000 m³ of sea water (FORTI, 2014). Due to the tropical climate of the area (characterized by dry seasons and a few sudden rainstorms), the flow regime within the cave dramatically changes from less than 0.2 m³/s to much more than 10 m³/s in only a few hours during and just after heavy rainstorms.

The very high external relative humidity, together with the extremely low daily temperature fluctuation and the presence within the cave of a wide free water surface, greatly inhibit the evaporation processes that are limited to places where relatively strong air currents occur (up to 1.5 m/s displacing over 100 m³/s). Conversely, at some sites within the cave system, it is sometimes possible to see active condensation processes with the development of large clouds, the genesis of which is induced by cold air currents coming from the upper cave levels (BADINO, 2017) or when relatively cool percolation water coming from the top of the mountain rapidly reaches the main cave passages.

In the last two years, thanks to the international multidisciplinary research project *Support for sustainable eco-tourism in PPUR (Puerto Princesa Underground River)* (DE VIVO ET AL., 2017) it was possible to make a detailed analysis of the Natuturingam speleothems.

This study, even still in progress, put in evidence the presence of several uncommon formations, among which a few are absolutely novel for the cave environment. Moreover, it was proved that the evolution of all those speleothems is strictly controlled by the tropical climate of the cave.

In the international cave literature, papers dealing with tropical speleothems are scarce and therefore this outlook on the different speleothems observed in the Natuturingam cave, beside the importance of the single described form, may result of a general interest.

SPELEOTHEM PECULIAR TO TROPICAL CAVES

Speleothems morphologies are mainly controlled by the type of water flow feeding them (HILL & FORTI, 1997). This characteristic has allowed to define the “normal” (simplest) shape of the most common speleothems such as stalagmites, stalactites etc. on the basis of the in time evolution of supersaturation during the flow of the feeding water over the speleothem itself.

This modeling has been always done considering a stationary homogeneous flow, but most of the real speleothems evidence more complex morphological patterns, because this boundary condition cannot sometimes be maintained (BADINO ET AL., 2017).

This is particularly true in the tropical caves where the climate is often characterized by short but strong rainstorms followed by relatively long dry periods. In these conditions peculiar speleothems may develop, the most common of which are surely the stalactites with very large internal feeding tube (up to several decimeters in diameter) and the related hollow stalagmites below, normally referred respectively as “showerhead” and “bath tubes” (Fig. 2).

Anyway it was recently proved that a series of sudden variations in the feeding flow may induce variations on the external shape of all the most common speleothems (stalactites, stalagmites, flowstones etc.), giving rise to sub-horizontal steps, indented surfaces (organ pipes)



Fig. 2 - Natuturingam Cave: A - Daylight chamber: a waterfall escaping from a “showerhead” during a rainstorm (Photo Vittorio Crobu, La Venta); B - Upper branches: a “bath tube” with its giant internal hole during a dry period. (Photo by Marco Vattano, La Venta).

or sequence of upside down conical surfaces (BADINO ET AL. 2017). All these forms are controlled by the transition from a laminar to turbulent flow over the surface of the given speleothem. This mechanism is not restricted to the tropical caves, but in the cavities interested by such type of climate the hosted speleothems often exhibit particularly exasperated forms, as in the case of the “giant jellyfish” observed along the Australian branch in Natuturingam cave (Fig. 3).

Its development was proved to be totally controlled by the sudden variations feeding regimen underwent (FORTI 2017b). In fact, during floods, the water flows over this speleothem in an extremely fast manner, therefore a protruding, slightly inclined, surface develops from which most of the feeding water drip down.

On the contrary, the part of speleothem under the “umbrella” is interested by water flow only when the floods decrease, at the beginning of a dry period. The progressively smaller elongated bulbs are the direct consequence of the alternation of laminar and turbulent flows, the latter occurring just before the beginning of a new bulb.

A few other speleothem types are characteristic of the tropical environment: among them the most common are the scintillites and the triangular cups. The scintillites were firstly described in the Jewel Cave, USA (DEAL 1964), where they consist of quartz. Later also calcite scintillites were observed in different parts of the world. The characteristics of these speleothems (normally flowstones but also columns or stalagmites) are to have their surface sparkling due to the presence of well-developed crystals. They correspond to the faces of cal-



Fig. 3 - Australian branch: thanks to the Palawan climate, this big complex flowstone evolved resembling a “giant jellyfish” (Photo by Vittorio Crobu, La Venta).



Fig. 4 - Natuturingam cave, Gaia Branch: the “frozen stars” scintillites, giant flat calcite crystals giving rise to the “frozen stars” sparkling flowstone (Photo by Natalino Russo, La Venta).

cite epitaxial crystals developed on the smaller ones forming the structure of the last layer of the speleothem, when it was completely dried up (FORTI, 2017b).

It is evident that the possibility of the development of such crystal planar surfaces may be achieved also in caves outside the tropical areas, but the peculiar Palawan climate proved to be ideal for the growth of this speleothem, allowing the evolution of giant scintillites (“frozen stars” up to several centimeters) like those present at the beginning of the Gaia Branch (Fig. 4). The possibility to grow for these big crystals is given by the long dry periods in between strong rainstorms during which due a constant 100% relative humidity is maintained. Extremely slow evaporation occurs, which in turn is sometimes interrupted by periods of active condensation, which cause a partial re-dissolution of the smallest crystals. Thus, only few but large epitaxial crystals may develop.

Triangular cups are a relatively common spelothem type, developing inside swallow pools subjected to frequent total drying up; therefore the tropical climate enhances the possibility of development of such forms, which anyway are not restricted to that environment.

Triangular cups are small pans in the shape of an overturned triangular pyramid, each consisting of a mono-crystalline structure of calcite. These formations need very special boundary conditions:

- 1- rare but rapid supply, with slightly supersaturated water and
- 2- rather long dry periods to allow capillary uplift and slow evaporation only from the outer edges

This process will eventually cause the complete sealing of the inner hole, giving rise to horizontal shelfstone, which progressively molds the former cups together. Triangular cups are small pans in the shape of an overturned triangular pyramid, each consisting of a mono-crystalline structure of calcite.

This speleothem type is abundant in the upper galleries of Natuturingam cave where it can be seen in different occurrences as single hyaline small cup, or as top portion of calcite megacrystals or as a rather completely transformed flat floor of triangular crystals (Fig. 5).



Fig. 5 - Natuturingam cave: A: Carlita's branch, triangular cups partially filling a swallow pool (Photo Marco Vattano, La Venta); B: Gaia Branch: a group of triangular cup partially transformed into a flat flowstone (Photo Alessio Romeo, La Venta); C: triangular, rhombic and trigonal depressions (depending on the shape of the calcite monocystal) developed on top of euhedral calcite crystals (Photo Marco Vattano, La Venta).

Triangular stalagmites (Fig. 6) may grow under the same boundary conditions allowing the evolution of the triangular cup but they are much more rare: in fact they were until now reported only from a few caves of our planet (HILL & FORTI 1997). During the expedition of November 2016 (DE VIVO & FORTI 2017a) one of the best occurrences of triangular stalagmites in the world has been observed in the Carlita's branch.

They consist of mono-crystalline structures of calcite, but morphologically they are the exact opposite of triangular cups, being filled triangular pyramids. In this case, their shape is controlled by the usual "teeth habit" of calcite monocystals. Evaporation is still the dominant



Fig. 6 - Natuturingam cave, Carlita's Branch: a group of triangular stalagmites (Photo by Vittorio Crobu, La Venta).

process, even if it is not possible to exclude a contribution of CO₂ diffusion from the solution. In this case, however, the feeding must be much more constant, because there is not the possibility the formation of a “water tank” to maintain active the speleothems also during the dry periods. Finally, the dripping should not be too violent; otherwise, the impact would develop a rather flat top surface masking thus the triangular shape of the stalagmite top. These additional boundaries conditions explain why the triangular stalagmite is so rare.

SPELEOTHEMS RESTRICTED TO PPUR CAVE, BUT DESCRIBED IN PREVIOUS PAPERS

Beside the just described speleothems, several others are actually restricted to this cave and their location is reported in Fig. 1.

A peculiar drapery was the first to be discovered during the expedition of 2011, and the single one occurring in the base level of the cave (BADINO ET AL., 2016), just beyond the normal limit of the tourist tour. The peculiarity of this drapery is the presence of some sub-horizontal enlargements occurring on both sides of the speleothem at the same elevation. Due to its peculiar morphology (ribbed structure) this formation is currently unique in the world scene (Fig. 7).

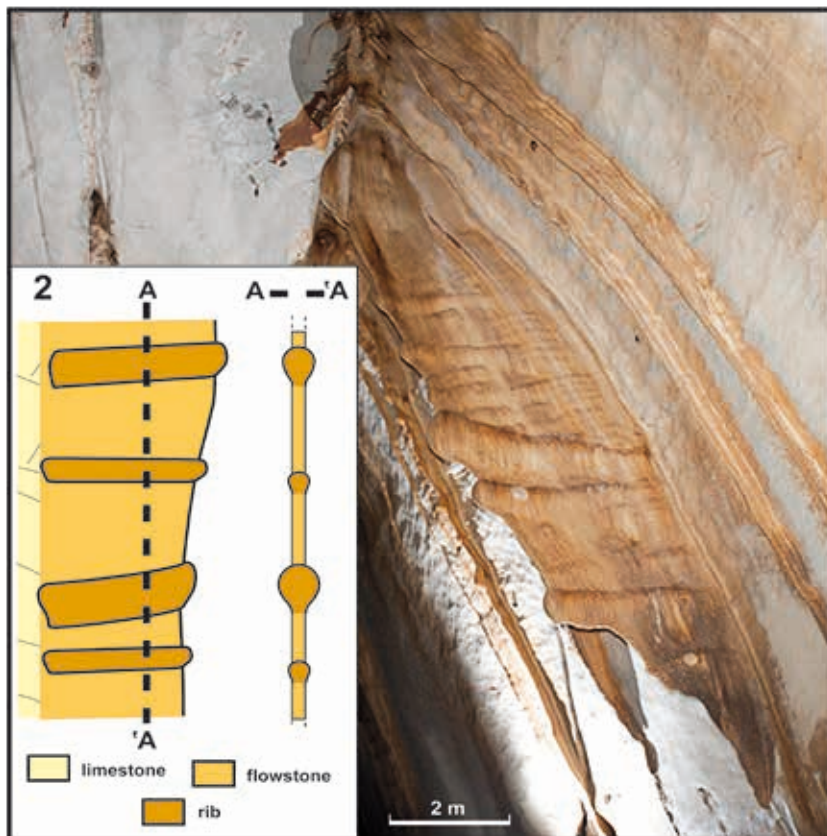


Fig. 7 - God's Highway: the giant “ribbed drapery” (Photo by Natalino Russo, La Venta).

Its genesis (BADINO ET AL. 2016) has been attributed to the particular water regimen feeding it, which varies dramatically from the dry periods to the flooded ones that follow heavy rains.

The close-to-horizontal ribs develop during the fast water flow induced by rainstorms which cause, in selected steady places of both drapery's sides, the transition from laminar to turbulent flow thus allowing a differential deposition where this occurs. Finally, the partial upward deflection of the largest ribs is induced by higher deposition occurring just above the point where turbulence begins and the efficiency of the just outlined process is proportional to the size of the ribs. Therefore the upside deflection is directly controlled by the rib size (BADINO ET AL. 2016).

All the other new speleothem' types are located in the upper branches (in particular the 150 years galleries and in the small branches diverting from it), where the effects of the heavy rainstorms on the cave microclimate is higher than along the flooded passages...

The cave grass is a peculiar type of calcite anthodite. They consist of monocrystalline calcite helictites, without internal feeding tube, which exhibit a rather sub-vertical development (Fig. 8).

For their genesis an accumulation of water into porous sediments is necessary, from which it is progressively released by capillary forces (FORTI, 2017a). The field of cave grass hosted by the 150 Years gallery is presently the most spectacular in the world due to the exceptional height (up to 60-80 cm) reached by a single grass string. This unusual development is due to the fact that this site is characterized by strong air flow during and just after the rainstorms,



Fig. 8 - 150 Years gallery: Partial view of field of calcite grass (Photo by Riccardo De Luca, La Venta); A: Close view of the tip of a grass string where the deposition of aragonite occurs close to the end by evaporation process (Photo by Marco Vattano, La Venta).



Fig. 9 - 150 Years gallery: the champagne flute calcite monocrystal helictite (Photo by Alessio Romeo, La Venta).

which facilitates the capillary rise of water over the outer surface of the anthodite. After each rainstorm all the water stored within the floor evaporates thus allowing the deposition of aragonite and/or hydromagnesite just on the tip of some of the grass strings (Fig. 8A).

Along the same gallery, not too far from the cave grass, a very strange single speleothem has been observed: the “Champagne flute” (Fig. 9).

It is a very special type of calcite helictite, which closely resembles a champagne cup, consisting of two completely different sectors.

The lower part is a normal helictite, structurally similar to a tubular speleothem, growing from the surface of the underlying speleothem, while the upper part consists of a very thin and elongated triangular cup. The abrupt morphological change at the beginning of the triangular enlargement was induced by a radical change in the feeding caused by the capture, during the high feeding regimen, of a dipping coming from the ceiling or from another speleothem hanging over the previously “normal” helictite

(FORTI, 2017a). During the dry periods the capillary uplift and evaporation of the water stored inside causes the progressive enlargement of the triangular hollow cup

In a remote location within the gigantic Magellan Chamber a curious ensemble of equidimensional rounded aggregates of calcite acicular crystals grew on a flat mud surface (Fig. 10) and these rounded aggregates, resembling sea-urchins on a beach, were never seen before.

Their development is induced by the presence of a rather horizontal muddy surface, over which a water layer flows during the rainstorms, thus exposing some small pebbles. During the following dry period capillary uplift and evaporation causes the development of small crystals just on top of the pebbles. Finally, alternation of dry and wet periods brings to the evolution of rounded acicular aggregates because the sea-urchin can expand in all directions (FORTI 2017b).

The flat mud surface, the random location of the pebbles over which the radial aggregates developed, and their dimension at the time of their discovery are the responsible for the curious and strange shape which suggested the name given to these speleothems.

Anyway, it must be stressed that, the progressive enlargement of the sea urchins will cause the coalescence of some of them. Therefore the final stage in the development of the sea urchins on the beach will consist in the evolution of a flat “carpet” of acicular crystals as in the lower part of the small gour of Fig. 10A.

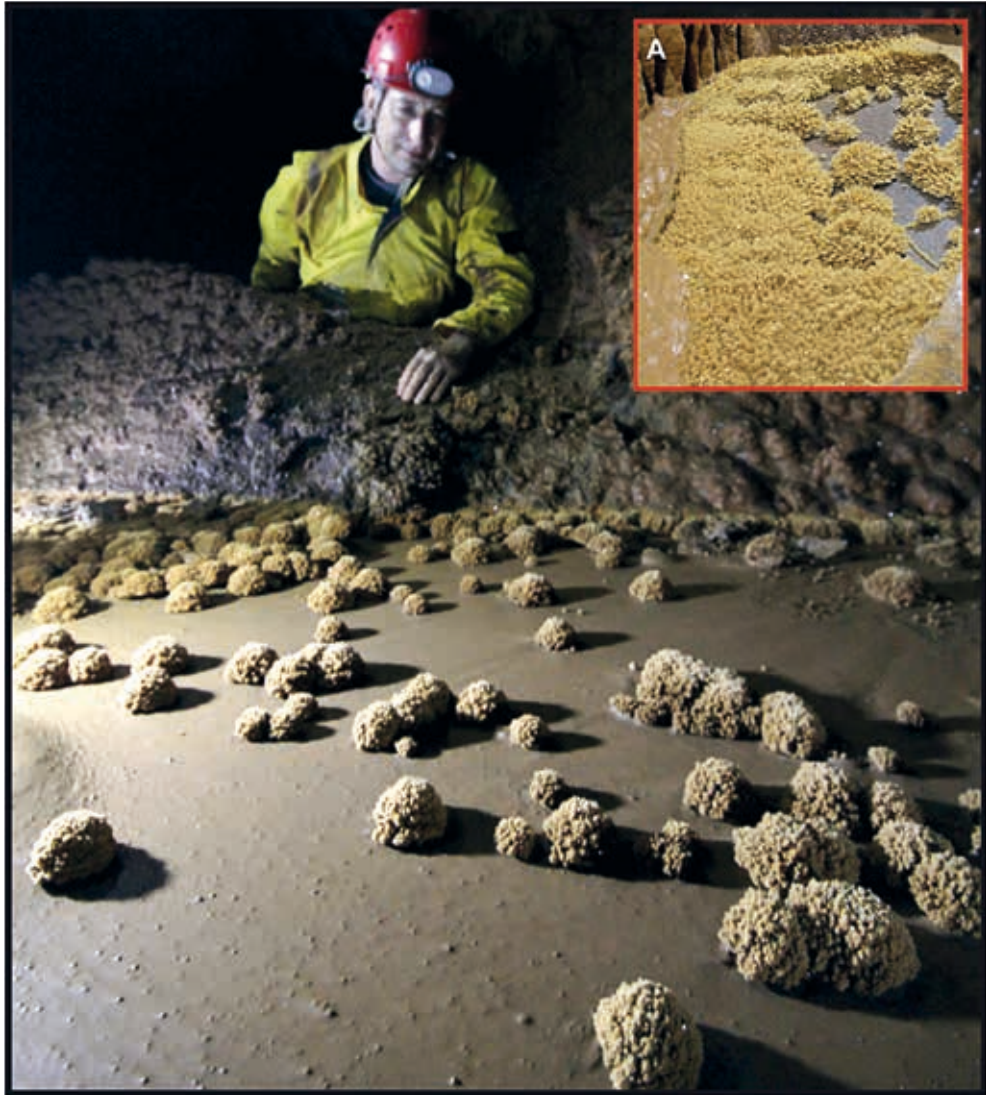


Fig. 10 - Natuturingam cave, Magellan Chamber: “the sea urchins over the beach” (Photo by Riccardo De Luca, La Venta); A: a small gour in which sea urchins started to coalesce (Photo by Tullio Bernabei, La Venta).

STILL UNDESCRIBED NEW SPELEOTHEMS TYPES RECENTLY FOUND IN THE PPUR

The very high number of uncommon speleothems growing inside the Natuturingam cave, suggested to insert a specific research field on this topic in the project *Support for sustainable eco-tourism in PPUR (Puerto Princesa Underground River) - Project 2016-2017*.



Fig. 11 - Gaia branch: the hyaline calcite rhombohedrons edging a gour which is fed by the same water flowing over the red flowstone above it (Photo by Alessio Romeo, La Venta).

Therefore the last two expeditions to Palawan (DE VIVO & FORTI 2017, DE VIVO ET AL. 2017b) were partially devoted to the research and the study of possible new speleothems within the Natuturingam cave.

During these expeditions five new peculiar speleothems have been found worth to be discussed in detail: 1) the hyaline calcite crystals over a red flowstone; 2) the lens-shaped and cylindrical cave pearls; 3) the spheroidal calcite monocrystals; 4) the spiked mace stalactite and 5) the calcite macro-crystal cup over mud pyramids.

1) *The hyaline calcite crystals over a red flowstone*

Just after the climbing allowing the access to the 150 Years gallery there is a highly decorated zone with huge red to red-brown flowstones: just at its foot there is a pool surrounded by perfectly transparent big calcite crystals (Fig. 11). But the gour is clearly fed by the same water coming from the red flowstone.

Two are the concurring mechanisms (Fig. 12) avoiding the crystals to assume the same color of the flowstone: 1) the rapid oxidation of the organics in contact with the cave atmosphere and 2) the very slow growth of the crystals.

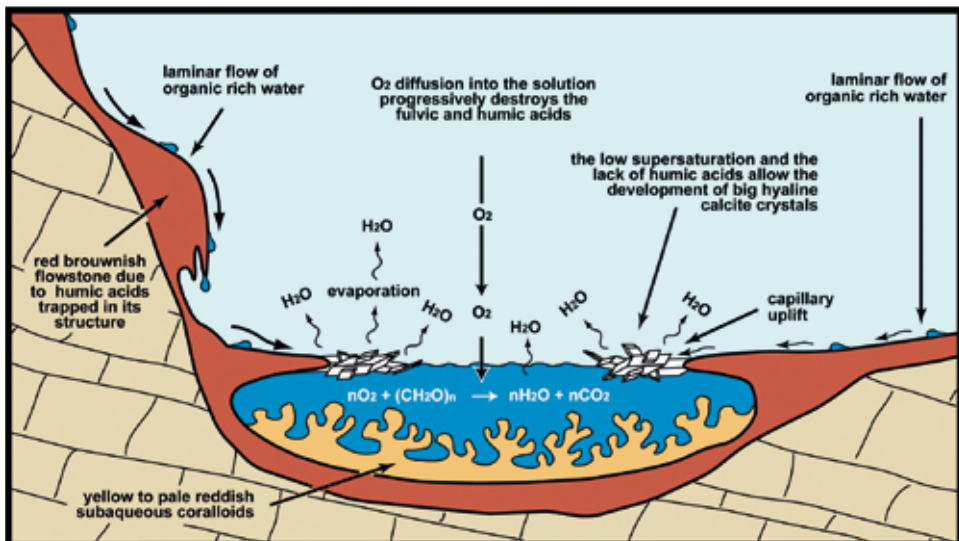


Fig. 12 - Genetic sketch for the development of the hyaline calcite crystals of the Natuturingam cave.

The red colour of the big flowstone is the consequence of the fast seepage of the water coming from a tropical forest, which is therefore rich in humic and fulvic acids, which are in turn trapped in the speleothem' structure (HILL & FORTI 1997). But why the calcite macrocrystals, even being fed by the same water, are hyaline?

The single controlling factor is the speed of growth, which is relatively fast for the flowstone (fed only during and just after the rainstorms) and from slow to very slow for the crystals (growing thanks to evaporation during the dry periods). This because the crystallization process promotes the expulsion of any kind of impurities from the crystal lattice.

The slower the process the biggest the developed crystals thus it is obvious that a high portion of the humic and fulvic acids are trapped in the flowstone, characterized by the smallest crystal dimension. Lesser amount of impurities is trapped within the pale yellow coralloids on the bottom of the pool, because their evolution is surely slower and, consequently, the crystal size higher.

But the single crystallization process would be unable to totally avoid the presence of impurities within the structure of the big calcite rhombohedra.

Another factor in fact concurs to remove totally these acids from the solution feeding the crystals such is the oxidation process.

The calcite rhombohedrons develop due to the capillary uplift and slow evaporation, therefore very thin water films are in direct contact with the cave atmosphere for a relatively long time. In this manner the oxidizing processes have enough time to totally deplete the humic and fulvic acids before they can be trapped in the crystal lattice.

2) *The lens-shaped and cylindrical cave pearls*

Flat lens-shaped and/or cylindrical cave pearls have been observed along the 150 Years gallery (Fig. 13).

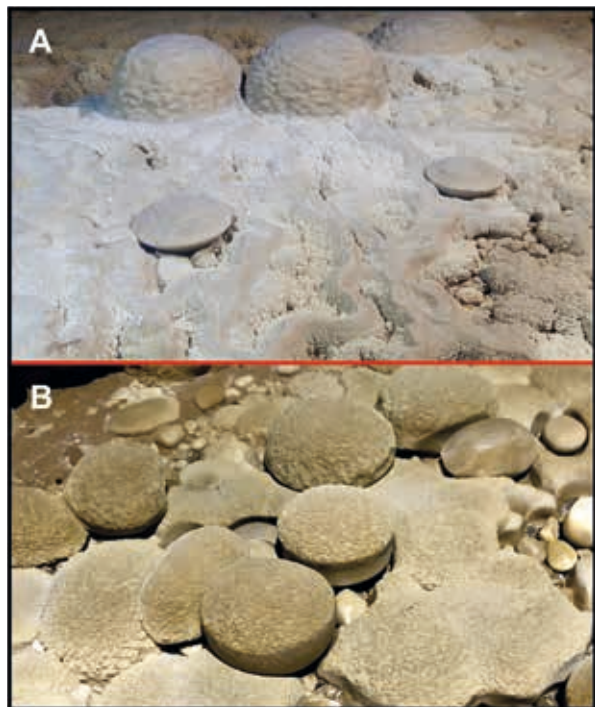


Fig. 13 - 150 Years Gallery: A) lens shaped and B) cylindrical cave pearls (Photo by Alessio Romeo, La Venta).

The shape of both lens-shaped and cylindrical pearls may be described as the coalescence of two geometrical forms: an upper flattened spheroidal cap which is common to both of these pearls, while the lower part of the lens-shaped pearl is an upside-down truncated-cone and a cylinder for the cylindrical ones. In the centre of the upper part of both these pearls microgours and microcoralloids may develop as a consequence of dripping. The external sides of truncated cones and cylinders, as well as their flat bases, always present clear erosional features.

Both these peculiar speleothems are very rare because their development requires several strict boundary conditions, which may be summarized as:

- 1 - Long periods of absence of dripping alternated with short but intense floods,
- 2 - Deposition characterized by the development of strongly porous calcite (often macro-crystalline) layers, which therefore may be easily eroded,
- 3 - Cave pearls upper surface never below air-water interface.

The first condition (which is a direct consequence of the Palawan climate) is responsible for the complete absence of water inside the pools, while at the beginning of a flood it is likely that the feeding water is still at least partially under-saturated.

During the short high flow periods, the cup and the hosted pearls and rock fragments undergo strong kinetic impulses with consequent partial erosion (enhanced also by a slight initial corrosion) of the soft porous calcite layers. After this event, capillary uplift and evaporation induce the total drying out of the cup, a condition that is maintained for relatively long periods until a new flood occurs and allows the development of the common upper spheroidal surface. The previously outlined combined processes also prevent very big pearls to be cemented to the cup bottom and allow their development even if they are never completely submerged by feeding water.

The diameter of the cup controls the dimension of the external circumference of the cave pearls, and consequently, also its flatness. In all cases, capillary uplift and evaporation may even make the pearl slightly larger than the cup's outer edge (Fig. 14). The period during which capillary uplift and evaporation are active is in turn responsible for the curvature of the upper part: in fact, the longer these processes last, the more elevated the centre of the upper spheroid will be.

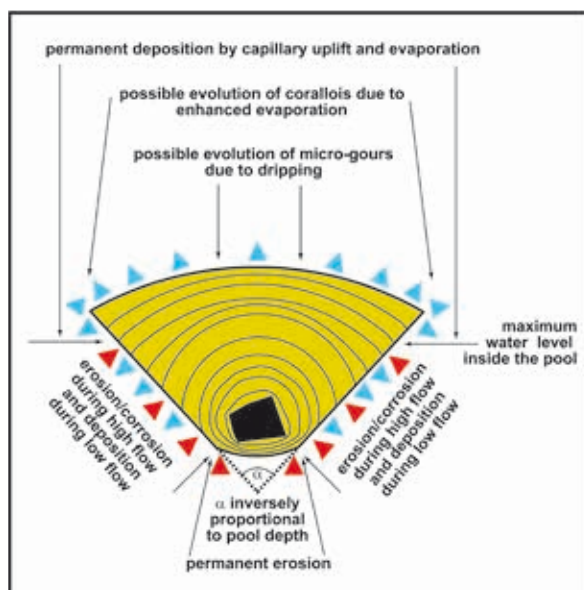


Fig. 14 - Theoretical section of a lens shaped cave pearl in which the different processes allowing its evolution are reported.

But why do sometimes lens-shaped pearls develop, and in other occurrences cylindrical ones are formed?

The sole controlling factor is the shape of the hosting cup: in fact, wide and shallow gour (with a depth of 1-2 cm as a maximum) cause the growth of more or less flattened lens-shaped pearls, while deeper ones tend to favour the development of progressively sharper cones (smaller α angle of Fig. 15).

The relationship existing between gour depth (at constant diameter) and the shape of the pearl is schematized in Fig. 15: it is evident that the depth increase is inversely proportional to the α angle, while it is directly proportional to the sub-horizontal erosional bottom surface.

Both these processes lead to the development of a perfect cylinder when the gour becomes deep enough.

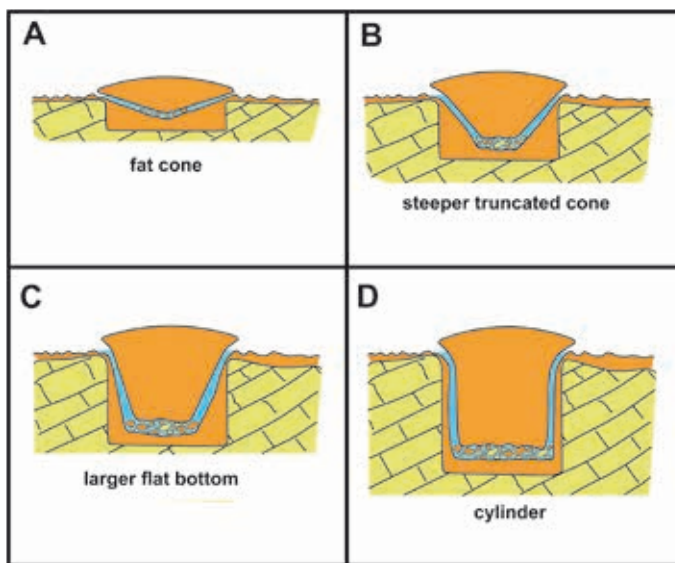


Fig. 15 - Relationship between cup depth and cave pearl shape. Increasing the depth makes the inverted flat cone (A) become steeper and truncated (B), and progressively the sub-horizontal flat corrosion surface in its bottom enlarges (C) until a perfect cone is developed (D).

3) *The calcite monocrystalline spheroids*

During the last expedition, a completely new type of speleothem was observed for the first time in the 150 Years Gallery. It consists of compenetrated spheroids of monocrystalline calcite (Fig. 16).

Most of the bigger ones exhibit a small stalk linking the spheroids to the mass of smaller compenetrated spheres laying behind them (Fig. 17).

Their evolution is controlled by the feeding mechanism, which is high and undersaturated during the floods and scarce and slightly oversaturated, but relatively long-lasting, during the dry periods. An important role in their development is also played by the condensation which is particularly active in this area where different air masses mingle together, giving rise to the phenomenon of underground clouds. During the wet periods, and thanks to condensation, even several days after the dripping is ceased, corrosion mainly dissolves the crystal apexes and edges, thus inducing the development of rounder surfaces, while the scarce supersaturation during the dry period only allows the epitaxial growth of the spheroids over the pre-existing crystals.

In this manner, starting from the small rhombohedral crystals of the limestone substratum, an aggregate of small, rather equidimensional, compenetrated spheres develops (Fig. 18).



Fig. 16 - Natuturingam cave, 150 Years Gallery: an almost perfect sphere of monocrystalline calcite (Photo by Marco Vattano, La Venta).



Fig. 17 - Natuturingam cave, 150 Years gallery: a rather big aggregate of spheroids with stalks growing over a flat macrocrystal calcite surface (Photo Marco Vattano, La Venta).

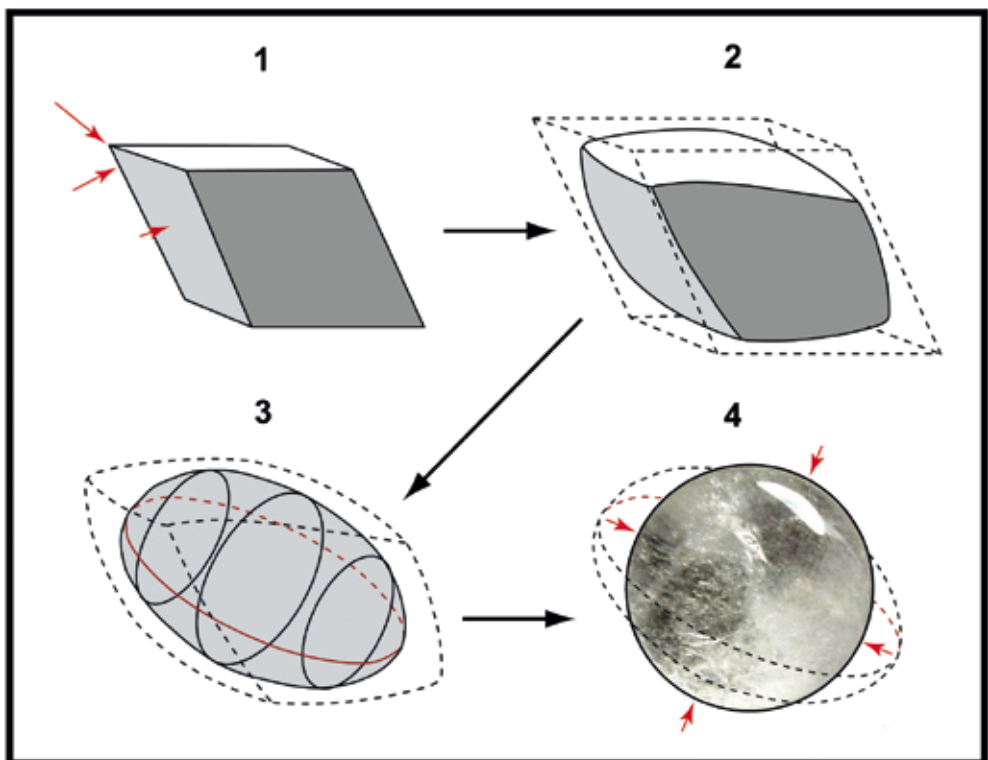


Fig. 18 - Stages in the development of a monocrystalline spheroid: the dissolution process is most effective on the vertex, while it is a minimum on the flat surfaces (red arrows in 1). Therefore, crystal faces tend to become bent (2). The process goes on (3) until a perfect rounded structure (4), where the dissolution process is equal in any direction, is formed.

Where the feeding is higher, stalks have the possibility to develop because, at the end of a wet period, under-saturated water is driven in a capillary way over the spheroids, thus inducing the partial dissolution of the lower part of them, while the subsequent evaporation on the upper part induces the progressive upward migration of the monocrystalline spheroids (Fig. 19).

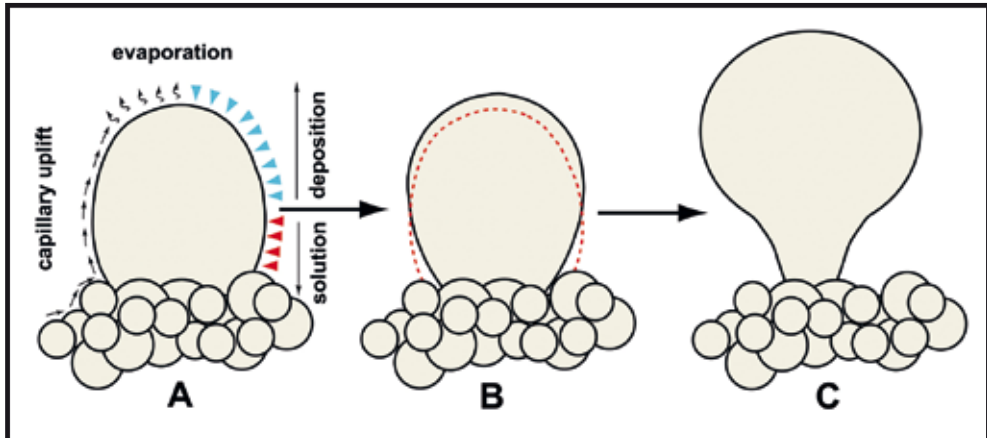


Fig. 19 - Mechanisms allowing the development of the stalk: capillary uplift of unsaturated water induces the partial dissolution of the lower portion of the big monocrystalline spheroid, while evaporation causes calcite deposition on its upper part (A). As a consequence, the lower part becomes narrower while the upper one enlarges (B). Hundreds of such processes lead to the genesis of a spheroid onto a stalk (C).

4) *The spiked mace stalactite*

The above described mechanism for the development of the stalks is confirmed by the presence in the same area of a broken macrocrystalline stalactite over which, thanks of the same process, long needles have developed (Fig. 20). Each needle is simply the partially corroded protrusion in the cave atmosphere of the radial calcite crystals originally creating the structure of the stalactite.

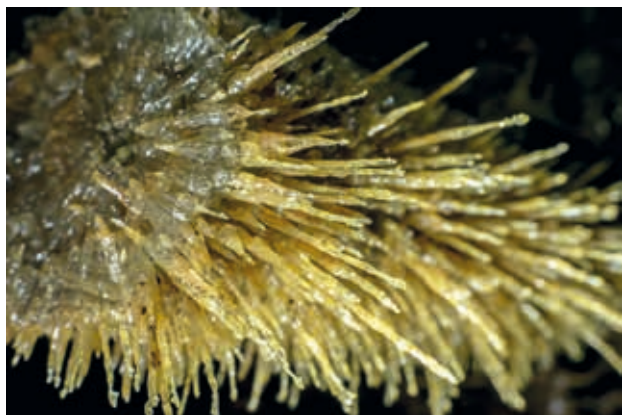


Fig. 20 - Natuturingam cave, 150 Years gallery: the broken “spiked mace” stalactite with the long radial needles (Photo by Alessio Romeo, La Venta).

It is not easy to uniquely define the different steps in the development of this strange speleothem owing to the fact that it has been found broken on the floor. In any case it is sure that the stalactite underwent at least two subsequent stages.

During the first one a "normal" stalactite formed and its internal macro-crystalline structure suggest a slow to very slow deposition, as a consequence of the feeding supply (occurring only during and just after the rainstorms) and of the cave microclimate (permanent 100% of RH), both hindering a fast evaporation processes (Fig. 21A).

The second step corresponds to a dramatic change in the feeding regimen with the water flow mainly induced by condensation (or unsaturated droplet impacts) over the external surface of stalactite.

If the stalactite was still hanged to the roof, this suggest that it possibly started to be within the activity cone of a showerhead, and the same situation should be realized also if the stalactite was already fell down.

In any case the change in feeding regimen induced a partial solution of the external surface during the floods (Fig. 21B), while, in the dry periods, the spikes started developing thanks to the capillary uplift and evaporation (21C). As soon as small spikes are present they become privileged points for both condensation-impact and capillary uplift-evaporation thus rapidly developing, while the original inner surface of the stalactite progressively dissolves.

Hundreds of B and C subsequent cycles gave to the stalactite the peculiar shape of a "spiked mace" (21D).

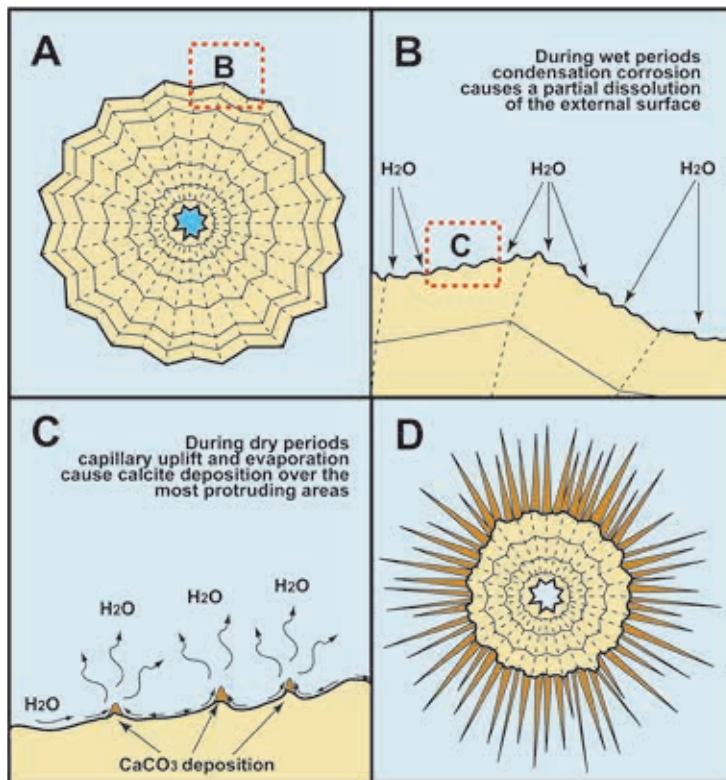


Fig. 21 - Sketch of the mechanism allowing to transform a normal macrocrystalline stalactite into a "spiked mace" (explanation in text).

5) *The calcite macro-crystal caps over mud pyramids*

Mud pyramids develop where several drippings impact over a more or less wide and thick mud surface (HILL & FORTI, 1997).

Normally pyramids are small ephemeral forms, being rapidly destroyed by drip impacts and subsequent rill erosion. Sometimes mud pyramids present on their tips pebbles, which protect them by further erosion. In fact they may survive longer only if their tips and steep conical surfaces are sheltered under a hard cap. The dimensions of each pyramid are controlled by that of the cap: the larger the pebble the taller and larger the pinnacle behind. Moreover, the presence of a cap somehow modifies the shape of the pyramid: in fact all what is laying just under the hard cap cannot be washed away even if the energy of the dripping is high. In this manner taller pyramids develop.

In the Mud Galleries there are large mud surfaces which allowed the evolution of several different mud forms, among which a peculiar type of pyramids also exists.

In fact, on top of some of these pyramids instead of a normal pebble, there is a cap consisting of an aggregate of calcite macro-crystal coralloids (Fig. 22).



Fig. 22 - Mud Galleries: calcite roses growing over mud pinnacles (Photo by Marco Vattano, La Venta).

The peculiar Palawan climate was the responsible for the genesis and development of these peculiar mud pyramids.

In fact, during rainstorms, and for a few hours after them, massive dripping impacts cause the development of small pinnacles. During the following, relatively long, dry period these embryonal pyramids become the privileged point for capillary uplift and evaporation which is enhanced by the upward air currents characteristic of these periods.

In this manner calcite precipitates just on the tip of the pyramid thus forming a small aggregate of calcite rhombohedrons. The pyramid size is controlled by a single factor: the amount of water available for capillary uplift and evaporation: more water means more calcite deposition and therefore larger hard cap, which in turn protect a larger and taller area from the erosion.

FINAL REMARKS

This surely not exhaustive outlook on the Natuturingam speleothems is anyway enough to state that this cave is extremely important also from the point of view of the hosted formations. In fact the presence of at about 10 completely new types of speleothems makes Natuturingan cave perhaps the most varied tropical cavity of the world in this specific field.

Nevertheless it must be said that most of exploration and research are still to be done. In the near future many other exciting discoveries wait for cavers and scientists who will decide to dedicate their efforts to this amazing karst system and its peculiar speleothems.

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